Renewable and Sustainable Energy Reviews 16 (2012) 3054–3064

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on the performance of Savonius wind turbines

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ARTICLE INFO

Article history:
Received 12 August 2011
Accepted 18 February 2012
Available online 22 March 2012

Keywords:
Savonius wind turbines
Performance
Aerodynamic coefficients
Review

ABSTRACT

This paper presents a review on the performance of Savonius wind turbines. This type of turbine is unusual and its application for obtaining useful energy from air stream is an alternative to the use of conventional wind turbines. Simple construction, high start up and full operation moment, wind acceptance from any direction, low noise and angular velocity in operation, reducing wear on moving parts, are some advantages of using this type of machine. Over the years, numerous adaptations for this device were proposed. The variety of possible configurations of the rotor is another advantage in using such machine. Each different arrangement of Savonius rotor affects its performance. Savonius rotor performance is affected by operational conditions, geometric and air flow parameters. The range of reported values for maximum averaged power coefficient includes values around 0.05–0.30 for most settings. Performance gains of up to 50% for tip speed ratio of maximum averaged power coefficient are also reported with the use of stators. Present article aims to gather relevant information about Savonius turbines, bringing a discussion about their performance. It is intended to provide useful knowledge for future studies.

Contents

1. Introduction

In recent decades, the global concern with the consequences of indiscriminate exploitation of non-renewable energy resources has increased. Pollution, global warming and reduction of political and economic viability in the use of non-renewable energy resources are some consequences of this exploitation. The use of renewable energy and decentralized power generation are alternatives to reduce the exploitation of conventional energy resources and its impacts, contributing to a sustainable development of societies.

The use of Savonius wind turbines in micro power generation is within of this context, but it is still not widespread. The Savonius turbines have been proposed as an alternative, considering the distributed power generation. Recent studies on Savonius wind turbines are developed with this purpose, as the research presented by Menet [1], where a prototype of a Savonius turbine is developed.

Unconventional devices, like the Savonius turbine, can be a solution for decentralized power generation, with low cost and reduced

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doi:10.1016/j.rser.2012.02.056

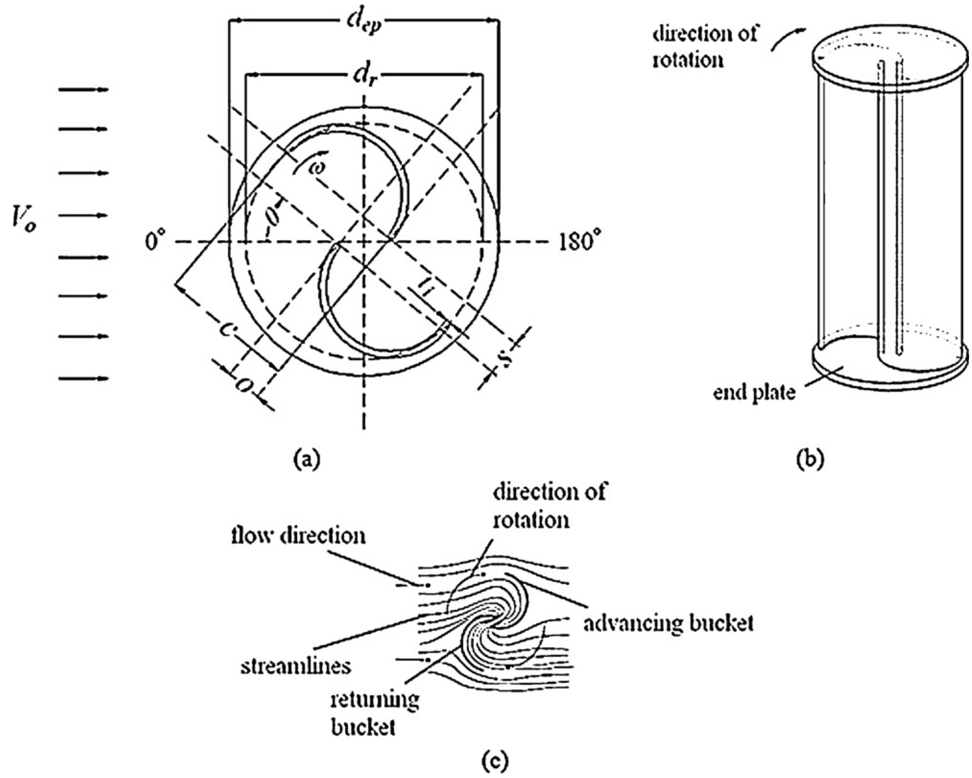

Fig. 1. Schematic representations for a Savonius rotor: (a) 2D representation; (b) 3D representation; (c) flow pattern on the rotor.

environmental impacts. The wind device developed and patented by S.J. Savonius in the 1920s has, among other advantages:

- simple construction with low cost;
- wind acceptance from any direction for the operation;
- low noise and angular velocity in operation;
- reduced wear on moving parts;
- various rotor configuration options;
- high static and dynamic moment [1–7].

It is considered that the Savonius turbines can be an interesting technological alternative to conventional wind turbines. Several studies, experimental, theoretical or numerical, on that device are found in technical and scientific literature. Different arrangements of Savonius rotor were studied, and it was concluded that each configuration provides significant different behavior. Published results demonstrate that Savonius rotor performance is affected by operational conditions, geometric and air flow parameters [1,4,8]. The range of reported values for the maximum averaged power coefficient includes values around 0.05–0.30, for most turbine settings [1–8]. However, there are some divergences among the conclusions that need to be investigated.

For these reasons, this paper aims to gather relevant information about Savonius turbines and carry out a review about published articles on performance analysis. It is intended to provide useful knowledge for future studies on this kind of wind turbine.

2. Savonius wind turbines

The Savonius rotor is a vertical axis wind turbine that operates essentially due to wind drag forces on their buckets, but lifting forces also contribute to mechanical power transmitted to the shaft. Fig. 1 shows characteristic parameters of a Savonius wind turbine with two semicircular profile buckets. In Fig. 1, t_i is the bucket thickness, c the bucket chord, o the buckets overlap, s the buckets spacing, d_r the rotor diameter and d_{ep} is the end plate diameter. The illustrated turbine is submitted to a wind with undisturbed velocity V_o, and rotation rate represented by ω. It rotates along the angular positions given by θ and, as the buckets move in their trajectories, they exhibit different contours to the wind, cyclically changing the coefficients of drag and lift. Thus, the torque produced by a rotor, at constant ω, cyclically varies during the rotation of the device. The operation mechanism of a Savonius rotor is very well explained in [4,5,8,9].

Nakajima et al. [8], explain the operation of a Savonius rotor by the main flows that occur on the rotor buckets during the operation. From flow visualization through a Savonius rotor operating in water current, the authors identified the main flow patterns that occur on the buckets of a Savonius rotor and which influence the operational characteristics of this device. These types of flow are shown in Fig. 2. Flow (I) produces a lift, (II) and (III) restore the pressure on the returning bucket concave side, and (IV) affects the power of the rotor. The attached flow (I) is observed at θ up to 45°. This attached flow (I) became the dragging flow (II) toward the concave side of the returning bucket. The former flow generates a lift and the latter restores the pressure on the concave side of the bucket, both contributing to the enhancement of averaged power coefficient. The vortex shedding from the tip of advancing bucket (V) occurs at θ equal to 90°. Also the shedding vortex from the tip of the returning bucket (VI) was generated. At θ greater than 90°, the shedding vortex (V) was separated from the tip of the advancing bucket and grew as flow to the downstream of the rotor. The flows identified by (IV) (V) and (VI) in Fig. 2, contribute to reduce the power of the rotor.

The power coefficient, C_P, presented in Eq. (1), is used to evaluate the wind turbine performance. This coefficient represents the fraction of extracted power from the total available in free stream of air flow at undisturbed velocity V_o that runs through the projected area of rotor at the flow direction, shown in Fig. 3.

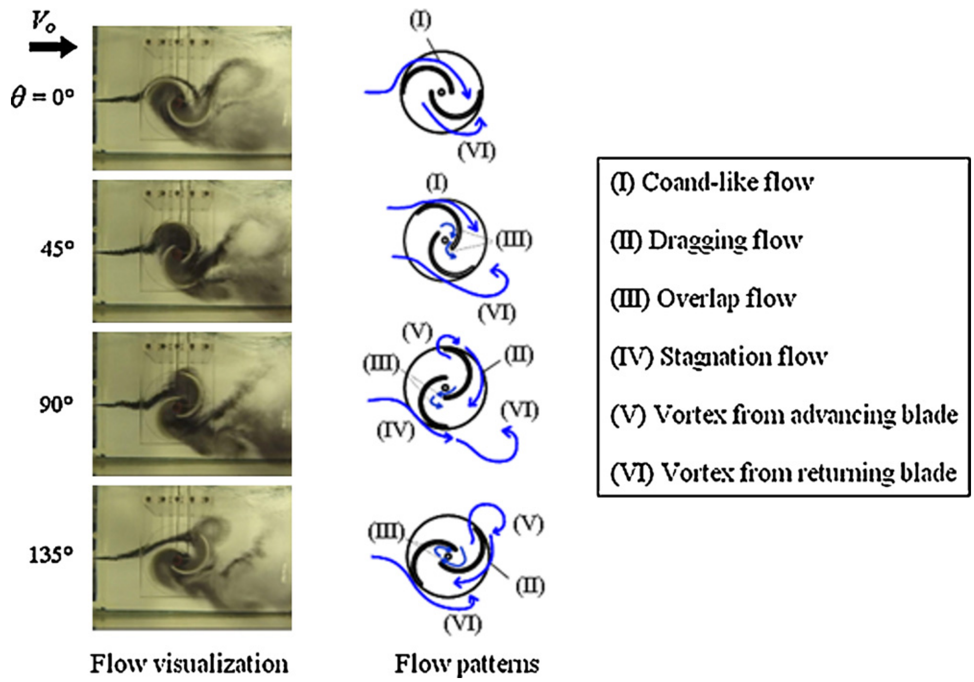

Fig. 2. Flows patterns on a Savonius rotor [8].

C_P is obtained adimensionalizing rotor power by the power provided by the air flow through the projected area of rotor at the flow direction [1–7]. In Eq. (1), P is the rotor power, M rotor moment, ρ air density, A rotor area, V_o undisturbed air velocity, r rotor radius, ω angular velocity, C_M moment coefficient and λ the tip speed ratio of de wind device (ratio between the tangential velocity of the bucket tip and V_o).

$$C_P = \frac{P}{P_{available}} = \frac{M\omega}{(1/2)\rho A V_o^3} = \frac{M}{(1/2)\rho A V_o^2 r}\frac{\omega r}{V_o} = C_M\lambda \qquad (1)$$

The performance characteristics of a Savonius wind rotor are usually obtained from field and wind tunnel experiments, or through the application of numerical methods that solve the conservation equations of the air flow [4–6,10]. According to Fernando and Modi [4], the theoretical prediction of Savonius rotor performance is difficult, by the complexity of the air flow around the machine and the mutual interference of the buckets.

Numerical research works about the operation of Savonius turbines, like those performed by D'Alessandro et al. [11], Altan and Atılgan [12] and Mohamed et al. [13], constitute a good alternative to obtain the performance characteristics and the visualization of the vector and scalar fields in the flow around the device, as shown in Fig. 4.

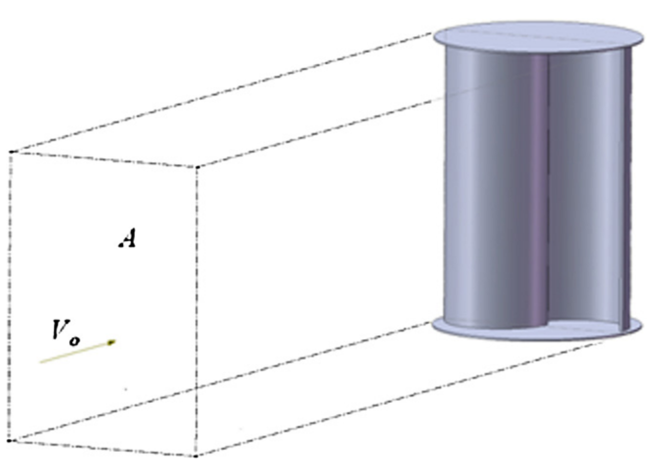

Fig. 3. Projected area of rotor at the flow direction.

Since the instantaneous Savonius rotor power cyclically varies along the rotation, averaged values for performance parameters (M, P, C_M and C_P), at a given rotational rate and undisturbed wind velocity, are commonly obtained and graphically expressed as shown in Fig. 5. Observing Fig. 5, one can verify that the values of averaged moment coefficients, after a certain value, decrease with the increase of tip speed ratio. This is because as rotation rate increases, the tangential velocity of the buckets tips exceeds the flow velocity, and then momentum is transferred from de turbine to the air flow, reducing the net moment of the rotor. By the use of these curves, different rotors and conditions can be compared and power curves of wind turbines can be designed according to the required operation. The Reynolds number, Re, for comparison is calculated by Eq. (2), where μ is the dynamic viscosity of atmospheric air and d_r is the rotor diameter.

$$Re = \frac{\rho V_o d_r}{\mu} \qquad (2)$$

The graphical representation of Fig. 6 is widely used in the literature to compare the performance of several existing types of wind turbines [15]. In Fig. 6, it can be verified that a Savonius rotor operates more efficiently at low tip speed ratios. The averaged moment coefficient as a function of tip speed ratio for wind turbines, shown in Fig. 7, can be obtained from those presented in Fig. 6. Observing Figs. 6 and 7, one can verify that a Savonius wind rotor has approximately the same operation range, in terms of tip speed ratio, that of the multi-blade wind turbines.

Over the years, many different configurations of Savonius rotor were invented. Fig. 8 shows some possible configurations. Each change in the shape of the rotor results in change in the performance curve. Many studies have been made about its performance, considering different parameters of the rotor and air flow. Table 1 shows some of these published studies. As shown in Table 1, there

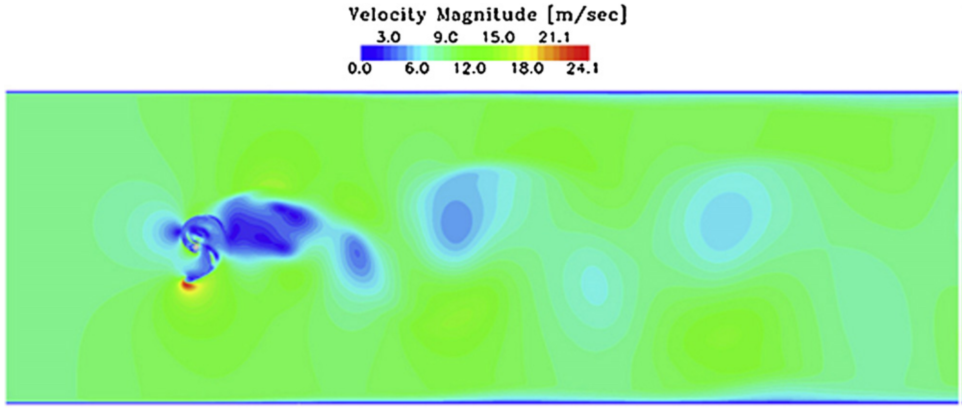

Fig. 4. Contour of velocity magnitude for Savonius rotor operating at λ = 0.735 [11].

are divergences among the results of the studies, and some aspects need to be better investigated.

3. Parameters that affect the performance of a Savonius wind turbine

The effect of end plates, aspect ratio, buckets spacing, buckets overlap and, number, rotor stages, buckets and rotor shapes, shaft and other accessories, Reynolds number, turbulence scales and stators are among the main parameters that affect the performance of a Savonius wind rotor.

3.1. The effect of end plates

An end plate is the simplest accessory that can be added to a Savonius turbine to increase its performance. As shown in Fig. 9, the addition of end plates on a Savonius turbine can greatly increase the maximum averaged power coefficient, $C_{P\,averaged}$. The turbine also operates more efficiently at higher tip speed ratios.

The plates at turbine ends prevent the escape of air from the concave side of the buckets to the external flow, keeping the pressure difference between concave and convex side of the buckets at satisfactory levels over the height of the rotor.

There is a consensus in the literature regarding the optimal size of this accessory. It is recommended a negligible thickness, relative to the height of the wind turbine. For the end plate diameter, the recommended size is equivalent to 1.1 times the rotor diameter. Very high diameters for the end plates can dramatically increase the rotor inertia [3,6,19,26].

3.2. The effect of aspect ratio

The turbine aspect ratio, A_r, is obtained adimensionalizing the turbine height, H, by its diameter, d_r. It is a decisive parameter for satisfactory performance. Savonius rotors with high aspect ratios have low losses due to the effect of the tips of the buckets. The aspect ratio growth of a Savonius turbine therefore has an effect similar to adding end plates. According to most studies on the

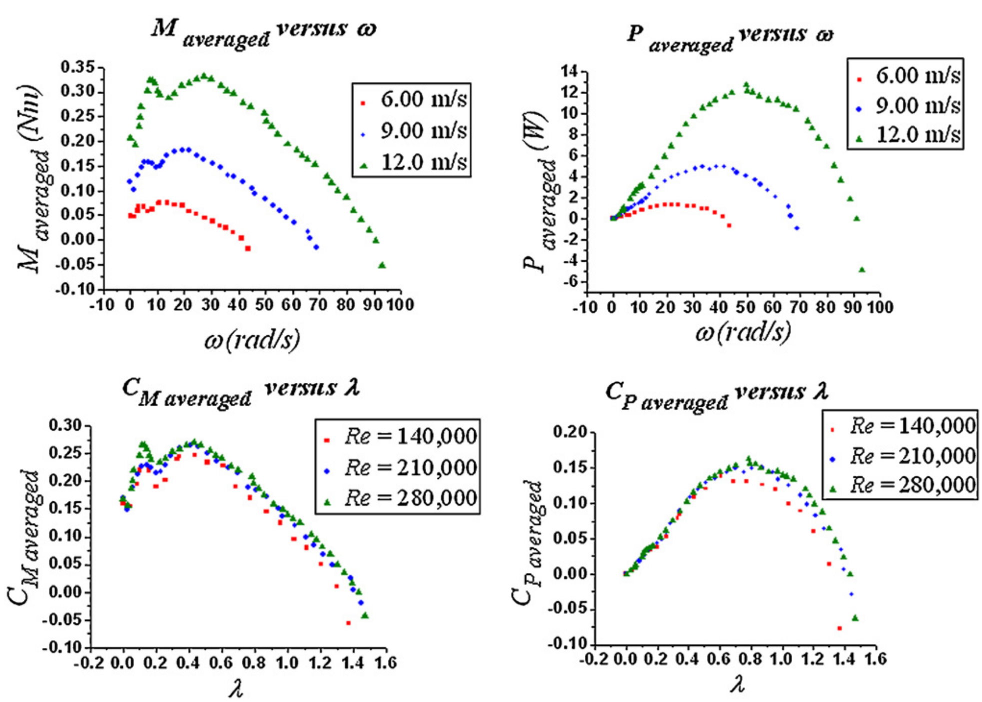

Fig. 5. Examples for averaged parameters obtained by wind tunnel tests.

Adapted from Hayashi et al. [14].

Table 1
Some studies already performed on turbines Savonius.

Authors	Study	Rotor profile	*Re*	Maximum $C_{P\,averaged}$
Simonds and Bodek [17]	Field measurements	Semicircular profile buckets	Variable	0.14
Blackwell et al. [18]	Closed section wind tunnel test	Semicircular profile buckets	867,000	0.24
Alexander and Holownia [19]	Closed section wind tunnel test	Semicircular profile buckets	188,000	0.15
Shankar [20]	Open section wind tunnel test	Semicircular profile buckets	19,600	0.23
Mojola [10]	Field measurements	Semicircular profile buckets	Variable	0.27
Fujisawa [5]	Open section wind tunnel test	Semicircular profile buckets	110,000	0.17
Rabah and Osawa [21]	Field measurements	Semicircular profile buckets	Variable	0.24
Kawamura et al. [22]	Domain decomposition method	Semicircular profile buckets	Not informed	0.14
Hayashi et al. [14]	Open section wind tunnel test	Semicircular profile buckets	280,000	0.16
Saha and Rajkumar [23]	Open section wind tunnel test	Twisted buckets	119,000	0.14
Saha et al. [6]	Open section wind tunnel test	Twisted buckets	61,000	0.32
Kamoji et al. [24]	Open section wind tunnel test	Semicircular profile buckets	120,000	0.18
Kamoji et al. [25]	Open section wind tunnel test	Buckets profiles shaped like a "hooks"	150,000	0.21
Nakajima et al. [8]	Tests in hydrodynamic canal	Semicircular profile buckets	110,000	0.28
Kamoji et al. [7]	Open section wind tunnel test	Helical rotor	201,958	0.20
D'Alessandro et al. [11]	Finite volume method	Semicircular profile buckets	294,000	0.25
Mohamed et al. [13]	Finite volume method	Semicircular profile buckets	Not informed	0.30

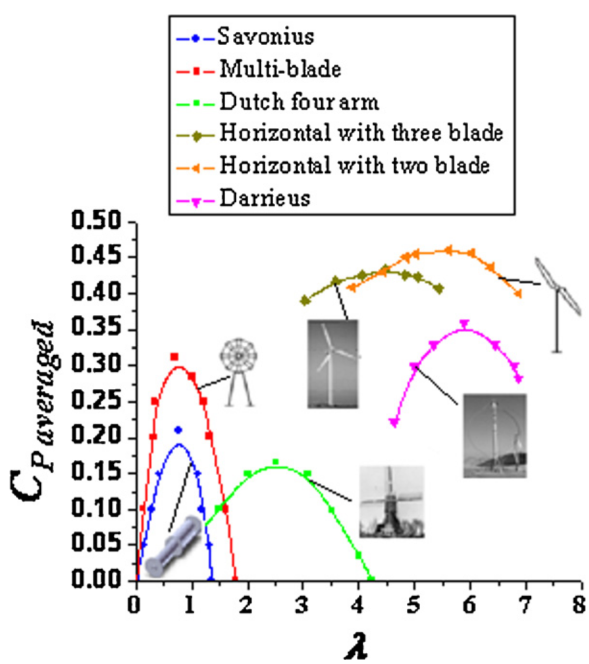

Fig. 6. Characteristic curves of $C_{P\,averaged}$ as a function of λ for various wind turbines. Adapted from Eldridge [15].

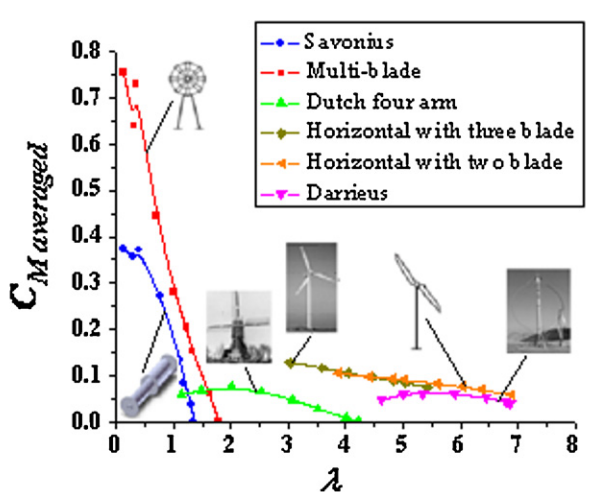

Fig. 7. Characteristic curves of $C_{M\,averaged}$ as a function of λ for various wind turbines. Adapted from Eldridge [15].

subject, values for aspect ratios of about 2.0 already give good results on the performance of Savonius rotors. In Fig. 10, where *s* is the buckets separation, *o* its overlap and *c* its chord, the effect of the turbine height growth for some configurations, at maximum power coefficient averaged, over the rotation, can be examined [3,6,19].

According to Vance [3] the aspect ratio of a Savonius rotor can also be adjusted to the needs of the rotational rate of the generation system (coupled secondary machine). As shown in Fig. 11, the turbine angular acceleration increases, while the rotor moment, *M*, and inertia of the turbine decrease with increase of the Savonius turbine aspect ratio. The trends shown in Fig. 11 can be obtained considering constants: projected area, weight of the device, average load providing moment, bearing friction, average lever arm by turbine radius, wind velocity, and two-dimensional flow on the turbine.

3.3. Influence of buckets spacing and overlap

The verification of the influence of the buckets spacing and overlap (*s* and *o* in Fig. 1, respectively), in the rotor's performance, was the major goal of several studies on Savonius turbines. Most studies conclude that a null buckets spacing gives the best performance of a Savonius wind rotor with semicircular profile buckets. For large buckets spacing, the air does not satisfactorily focus on the concave portion of the returning bucket, reducing the power of the turbine.

For the dimensions of the buckets overlap, there is not a consensus among the results obtained in published studies. According to Fujisawa [5], the optimum size for the buckets overlap is equal to 15% of the buckets chord size, as shown in Fig. 12. Blackwell et al. [18] conclude that this dimension is equivalent to a value between 10 and 15% of the chord size. Alexander and Holownia [19], and Mojola [10] indicate that values between 20 and 30% of the bucket chord size provide the best performance results. The values for maximum averaged power coefficient obtained by Alexander and Holownia [19], for various buckets spacing and overlap combinations, and aspect ratio of 2.4, can be seen in Fig. 13.

3.4. The effect of number of buckets and rotor stages

According to Vance [3], Blackwell et al. [18], Saha et al. [6] and Shankar [20], the oscillations of dynamic and static moment of a Savonius rotor, along the angular positions of the advancing bucket, can be reduced with the addition of buckets. With increase of the rotor buckets number, it decreases the ranges of values, for angular positions of the advancing bucket, where the rotor moment is low, since the probability of a rotor bucket to be in a position favorable to the extraction of momentum from air flow increases. This fact

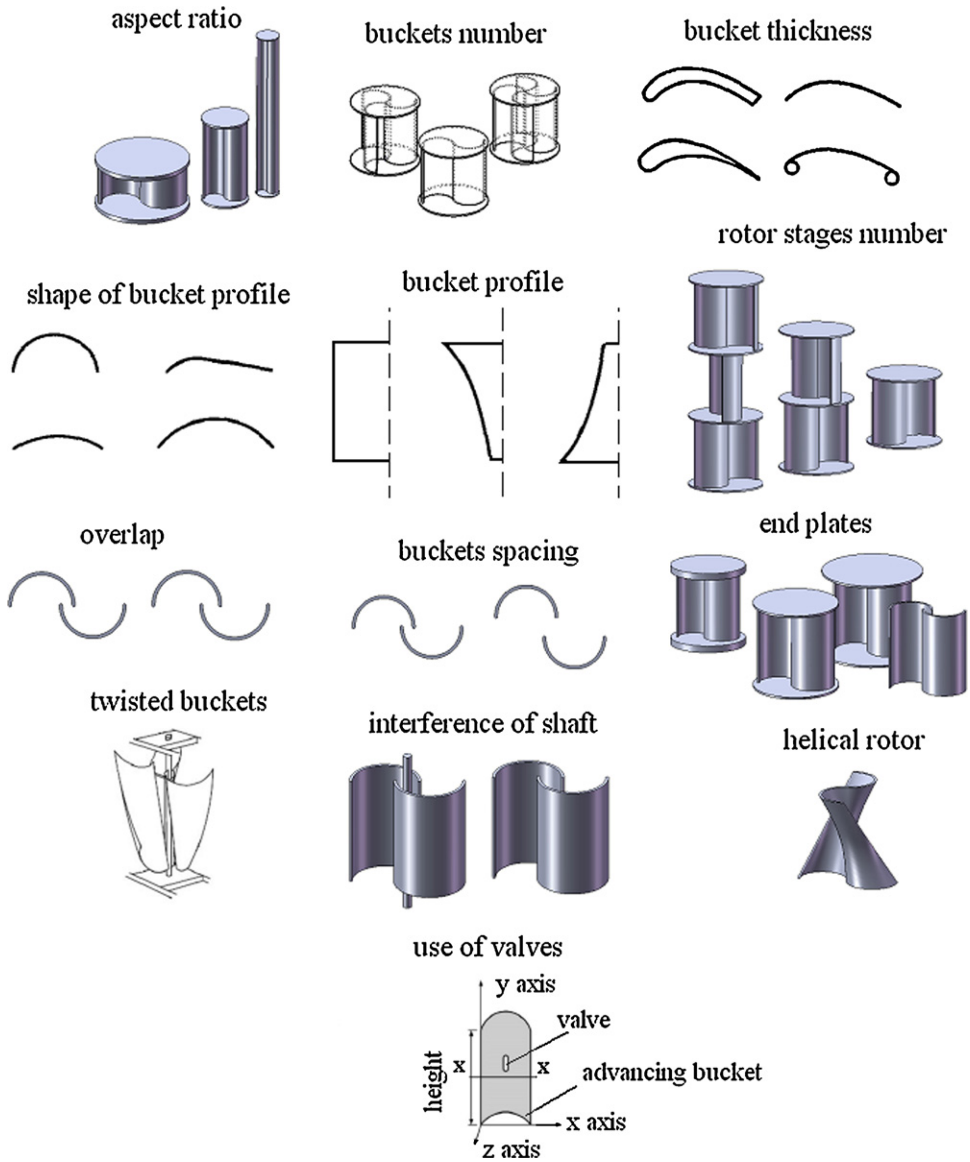

Fig. 8. Alternative arrangements for Savonius rotors [3,6,16].

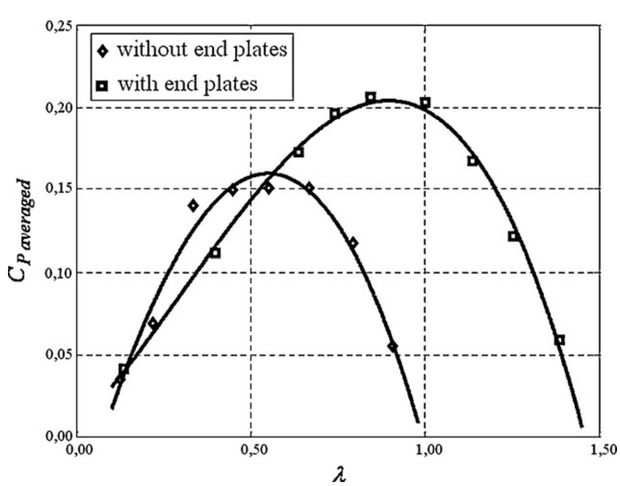

Fig. 9. End plates effect on the performance of a Savonius wind rotor [26].

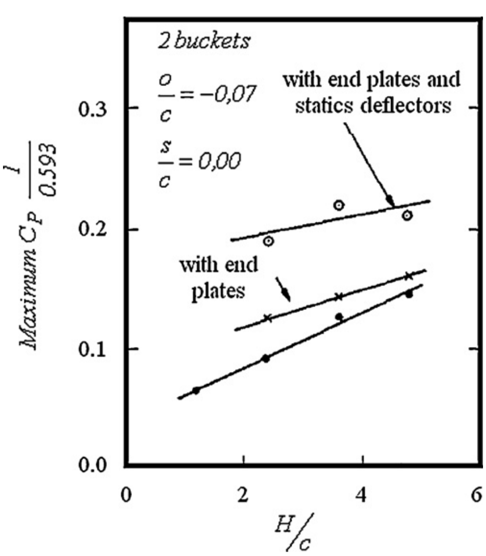

Fig. 10. Effect of aspect ratio on the performance of a Savonius wind rotor [19].

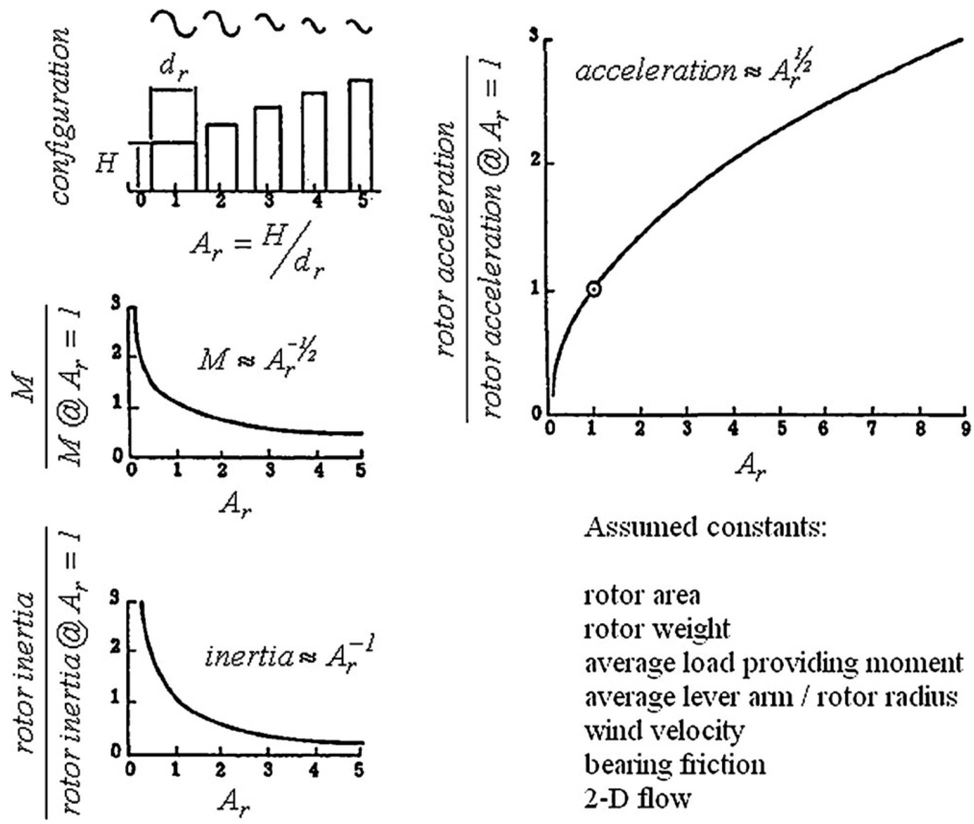

Fig. 11. Aspect ratio effect on the acceleration of a Savonius wind rotor [3].

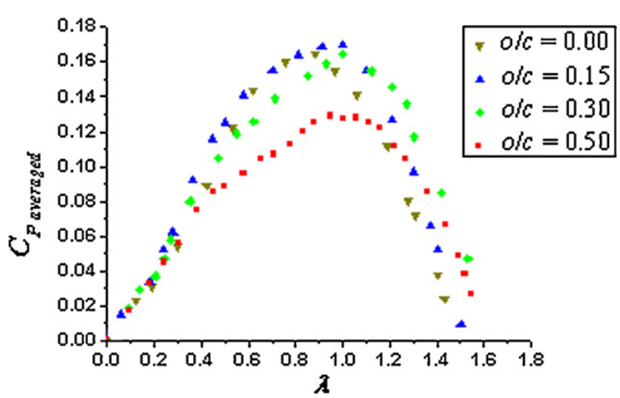

Fig. 12. Buckets overlap effect on the performance of a Savonius wind rotor [5].

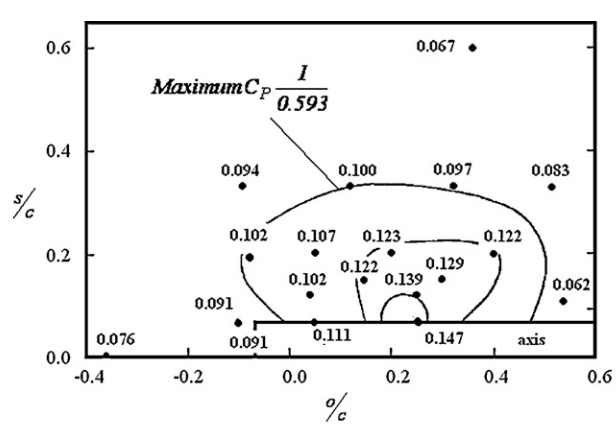

Fig. 13. Effect of buckets spacing and overlap on the Savonius wind turbine performance [19].

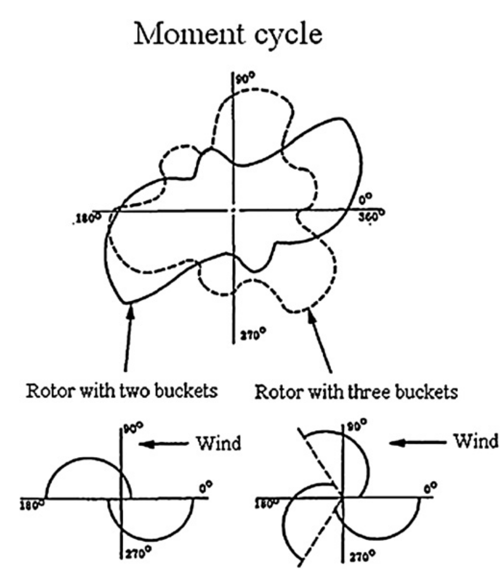

Fig. 14. Buckets number effect on the Savonius wind rotor moment [3].

can be seen in Fig. 14, which displays the cycles of rotor moment with two or three buckets.

The buckets addition on a rotor Savonius, however, reduces the maximum averaged power and moment coefficients along the angular positions. This occurs because a bucket deflects the air flow that would focus on next bucket that, in turn, deflects also the air flow that would focus on the next bucket after it. This fact produces a “cascade effect” in which each bucket affect the performance of the following bucket. The result is that less amount of energy released by the moving air is converted into mechanical energy by

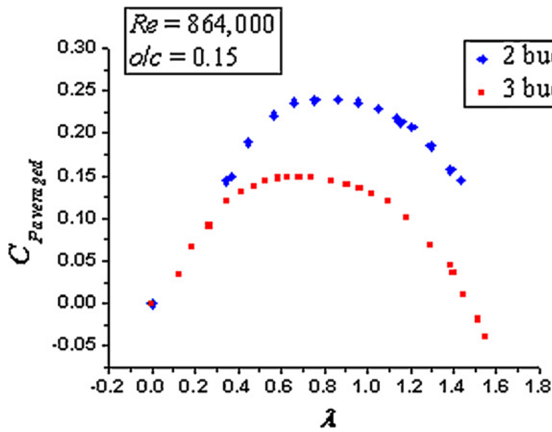

Fig. 15. Buckets number effect on the averaged power coefficient of a Savonius wind rotor [18].

the rotor [6,18,20]. Thus, a Savonius rotor with two buckets has a maximum averaged power coefficient, higher than the maximum averaged power coefficient of a Savonius rotor with several buckets. In Fig. 15, the influence of the buckets number in the averaged power coefficient can be analyzed.

According to Saha et al. [6] and Hayashi et al. [14], the solution to reduce the moment fluctuations, without significative performance loss, is the use of multiple stages, transmitting power to the rotor shaft, and operating with cycles lagged one another, as shown in the diagram in Fig. 16. Thus, several rotors with two buckets can operate in parallel, reducing the moment fluctuations. The result of this kind of operation can also be illustrated by the graphic representation of Fig. 17.

3.5. Buckets and rotor shapes influence

An infinite number of buckets and rotor shapes combinations can be obtained, as shown in Fig. 8. The performance curves of the turbine will suffer interference for each type of bucket and rotor.

Among the most studied profile options for buckets are the profiles shaped like a "hooks", as shown in Fig. 8. This bucket configuration was studied by Kamoji et al. [25], who obtained a value of 0.21 for the averaged power coefficient of a turbine with that kind of bucket against the value of 0.19 obtained by them for the averaged power coefficient of a rotor with buckets of semicircular profile. Rotors with buckets shaped like a "hooks" have slightly higher moments due to air flow to be directed more to the tip of the buckets.

Another commonly studied shape is the twisted bucket, as that of the explanatory scheme of Fig. 8. A rotor with buckets of this type produces more moment than a device with semicircular

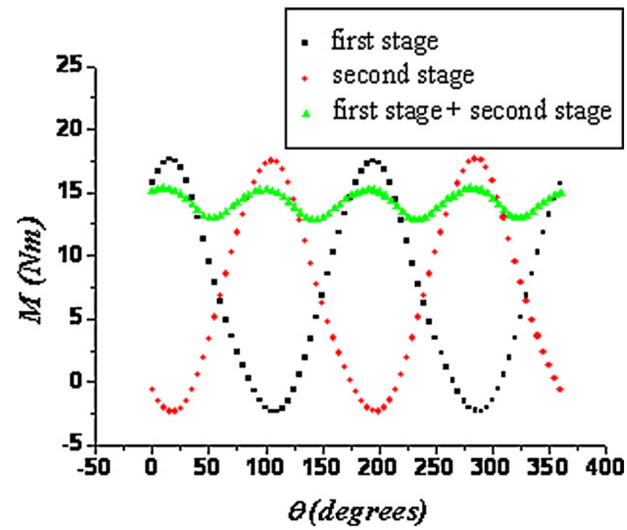

Fig. 17. Sum of moment cycles on a two stage rotor [16].

Table 2
Influence of Reynolds number on static moment coefficient at $\theta = 0^\circ$ [16].

Re	C_M
43,350	0.09
216,750	0.17
433,500	0.20
650,250	0.21
867,000	0.22

profile buckets, due to the same increase on the moment occurred on a rotor with buckets shaped like "hooks". Saha et al. [6], obtained values of 0.31 for averaged power coefficients for rotors with twisted buckets, and 0.29 for rotors with semicircular profile buckets.

The helical Savonius rotor is a rotor shape widely studied. A helical Savonius rotor, as can be seen in Fig. 8, can be understood as a rotor of infinite stages, with negligible height and lagged one another by angles that tend to 0°. The helical rotor effect on performance curves is similar to the effect of adding multiple stages to the rotor. The moment oscillations at operation by using a helical rotor are reduced. However, the helical rotor performance does not differ significantly from the performance of a rotor with semicircular profile buckets, according to the study of Kamoji et al. [7].

3.6. Interference of shaft and other accessories

According to several previous studies on the performance of the Savonius wind turbines, a passing shaft provides interference in the

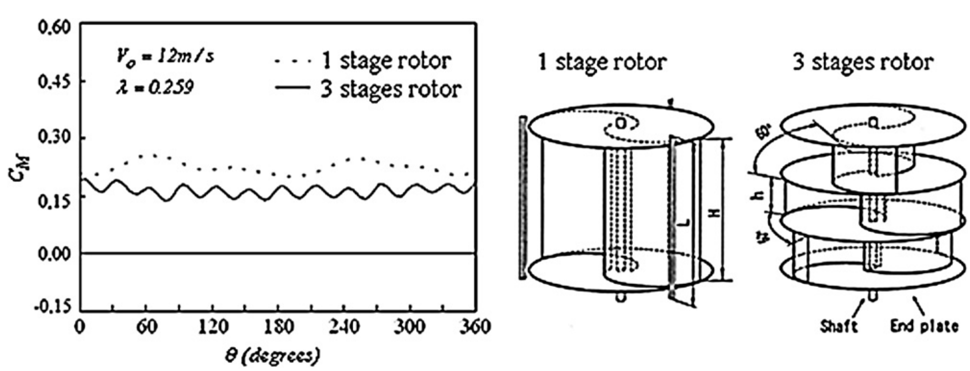

Fig. 16. Number of stages effect on the rotor moment coefficient [14].

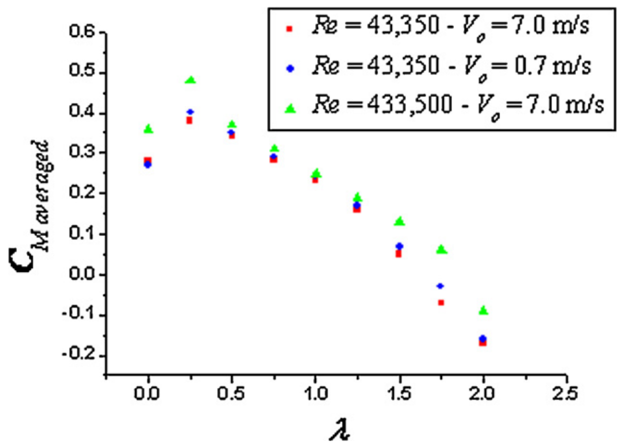

Fig. 18. Influence of Reynolds number on the averaged moment coefficient [16].

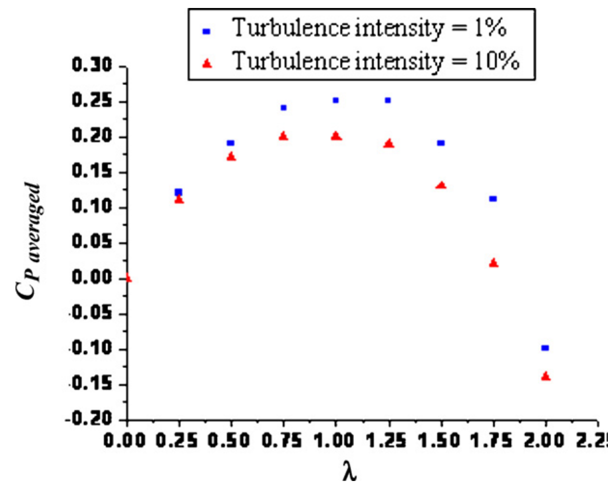

Fig. 20. Averaged power coefficient versus tip speed ratio at $Re = 867{,}000$ [16].

air flow through the spacing between the rotor buckets. This effect provides an efficiency reduction. However, a passing shaft can be used as an accessory to provide additional rigidity to the structure of the wind turbine. In this case, an increase in the buckets spacing and overlap should be applied, in order to compensate the blockade effect imposed on the air flow by the shaft [7].

Some accessories may be added to a Savonius wind turbine in order to increase the averaged power coefficient. Valves that only allow passage of air from the convex side to concave side of a bucket, reducing the bucket drag when it acts as returning bucket, according to Fig. 8. These valves were tested by Saha et al. [6], which obtained an increase on the averaged power coefficient for a two stage turbine with three semicircular profile buckets from 0.26 to 0.31.

3.7. Influence of Reynolds number and turbulence intensity

The Reynolds number, Eq. (2), affects the performance of the rotor operation, as can be seen in Fig. 5. According to Blackwell et al. [18], the increase of Reynolds number affects the phenomenon of boundary layer separation on the rotor buckets. An increase in this number delays the boundary layer separation on the convex side of the buckets, especially for values of angular positions close to 0 or 180°. Delayed separation of the boundary layer reduces the pressure drag on the returning bucket. This is due to increased pressure recovery that occurs, increasing of the lifting force participation on the resultant force for those angular positions, increasing the moment of the rotor.

In Fig. 18, the influence of Reynolds number on the Savonius wind turbine performance can be observed. The results presented in this figure were obtained in the study of Akwa [16], by the use of computational fluid dynamics. Akwa simulated also the effect of the increase of Reynolds number on a static rotor at angular position equal to zero degree. The effect of the Reynolds number increase on the static moment coefficient of a Savonius wind rotor can be seen in Table 2. In Fig. 19, this behavior can be analyzed by the absolute pressure on the rotor blades.

Another factor that may affect the performance of a Savonius wind turbine is the turbulence intensity, which characterizes the

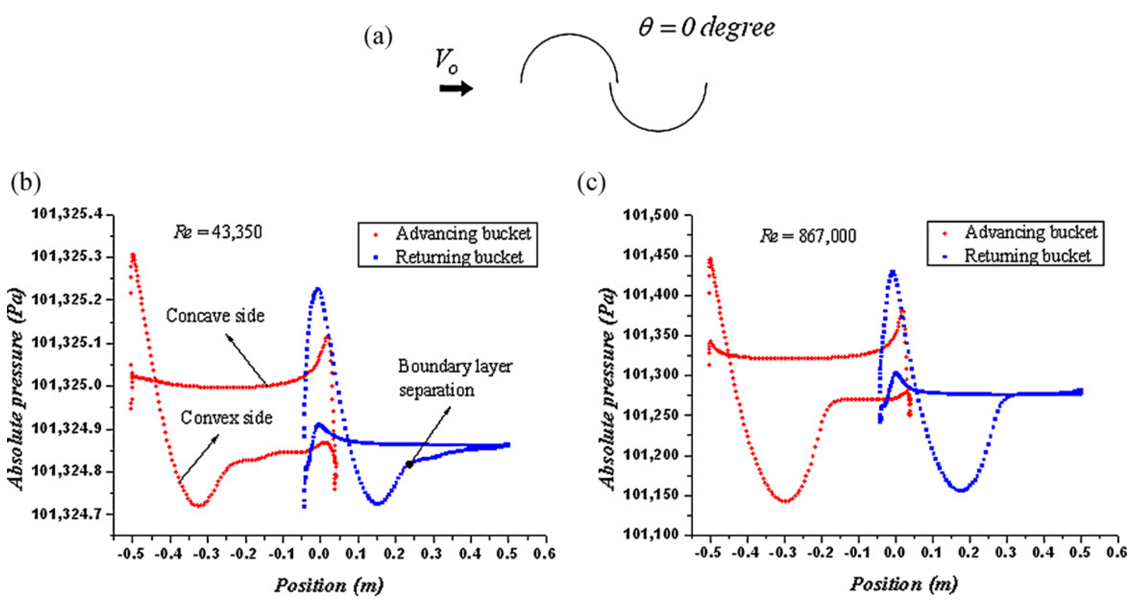

Fig. 19. Reynolds number influence on the absolute pressure around the static buckets at $\theta = 0°$: (a) rotor state; (b) absolute pressure on rotor at $Re = 43{,}350$; (c) absolute pressure on rotor at $Re = 867{,}000$ [16].

Table 3
Effect of free stream turbulence intensity on the maximum averaged power coefficient at $Re = 867{,}000$.

Study	Search type	Turbulence intensity (%)	Maximum $C_{P\,averaged}$
Blackwell et al. [18]	Closed section wind tunnel test	1.40	0.24
Cochran et al. [27]	Simulation by finite volume method	1.00	0.26
Cochran et al. [27]	Simulation by finite volume method	10.0	0.23
Akwa [16]	Simulation by finite volume method	1.00	0.25
Akwa [16]	Simulation by finite volume method	10.0	0.20

Table 4
Possible modifications to improve the performance of Savonius turbines with stators [13].

Design modification	Gain	Description and comments
Guide box tunnel [28]	50% (3 blades)	Complex three-blade design
Obstacle plate [29]	27% for design point	Only for standard, cylindrical blade
Frontal nozzle [12]	More than 40%	Small operating range ($\lambda < 1$)
Frontal guiding plates [30]	35% for design point	Need orientation into the wind

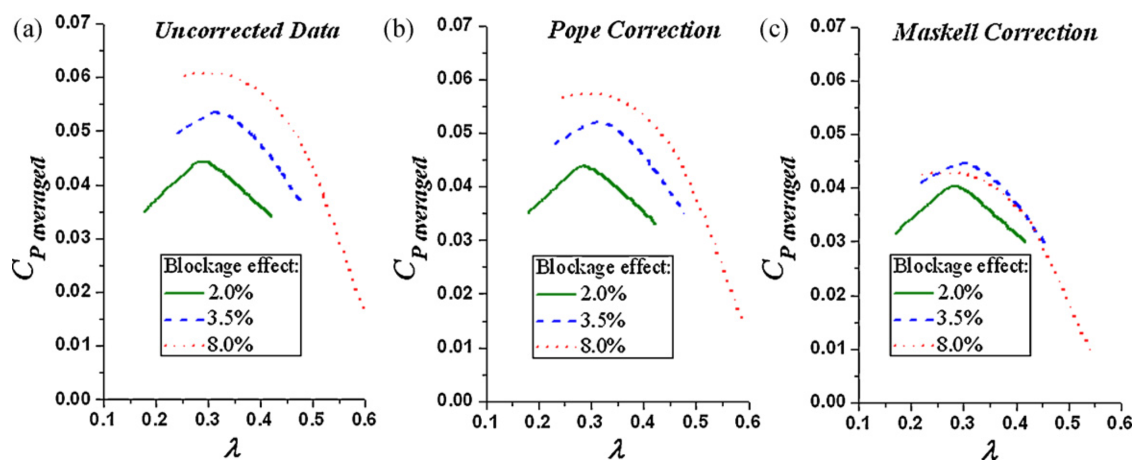

Fig. 21. C_P curves for three bucket Savonius rotors at 26.82 m/s free stream: (a) uncorrected data; (b) Pope method correction; (c) Maskell method correction. Adapted from Ross [31].

quality of the air flow around the device. Low quality air flow or turbulent flow affects the performance of wind turbine. In Table 3, one can see the decrease in the maximum averaged power coefficient as the turbulence intensity increase in the air free stream. The influence of turbulence intensity for other tip speed ratios was obtained in the study of Akwa [16], and may be seen in Fig. 20.

3.8. Influence of stators

Another way to provide performance gains is to use Savonius rotors with stators. Stators are static parts added to the turbines to deflect or concentrate the flow in a certain direction. Its simplest type is a blade which deflects the flow into the concave side of the advancing rotor bucket, reducing the negative moment exerted by the returning bucket, increasing the output net power of the device. Mohamed et al. [13], who performed simulations by computational fluid dynamics to optimize the geometry of a Savonius turbine with deflector blade, provide a review on the studies already done on this configuration. This review may be seen in Table 4. Mohamed et al. [13] obtained a performance gain of at least 30%, that is found for the full operating range ($0.3 \leq \lambda \leq 1.4$).

4. Conclusion and discussion

Numerous adaptations can be performed to improve the performance of a Savonius turbine, or to adapt the device use for any specific application. The variety of possible configurations of the rotor is a good characteristic of this machine. Each different arrangement of Savonius rotor provides performance interference.

Previous studies have shown that the performance of a Savonius wind rotor can be affected by geometric and air flow parameters. The parameters commonly studied that generally influence are: end plates, aspect ratio, buckets spacing, buckets overlap, buckets number, rotor stages, buckets and rotor shapes, shaft and other accessories, Reynolds number and turbulence intensity, and stators. As there is not an analytical method for Savonius turbines optimization, capable of predict the performance with good accuracy, experimental and numerical research works must be conducted for this purpose. This could be made by means of optimization algorithms. The algorithms would establish a functional relationship of the moment and power coefficients for each geometric and flow parameter. Eq. (3) describes this idea.

$$C_{P\,averaged} = f(\lambda,\ \text{geometric parameters, flow parameters}) \quad (3)$$

As shown in Table 1, there are differences among the results of the studies that have been made about the performance of Savonius wind turbine. Those differences are due not only to changes in the flow and geometrical parameters, as well as differences in the adopted methodology for each study. As investigated by Ross [31], an example is the methodology for determinate the undisturbed air velocity in wind tunnel tests with closed section. When a wind rotor is placed in the test section of a wind tunnel, the device causes a blockage effect on air stream, which alters the undisturbed wind velocity, which would be usually taken as the averaged velocity of the flow in the empty test section. Thus, a methodology to correct

the value of the undisturbed wind velocity should be adopted. Ross [31] obtained significant differences for the values of averaged power coefficients in experiments using different methods for correct the blockage effect, as shown in Fig. 21. According to Fig. 21, the differences between the values obtained with the method of Pope [32], in relation to those obtained with the Maskell [33] method, are above 25% for blockage effect equals to 8%.

Numerical studies on the performance of Savonius rotors can also present significant differences between the results obtained, even when the same geometric and flow conditions are reproduced. As explained by Mohamed and Thévenin [34], from the literature it is known that an accurate CFD simulation is a challenging task. This is due to the highly time-dependent and complex nature of the flow around the rotor. The averaged power coefficients must be independent of time step, maximum physical time of the simulation, spatial discretization and dimensions of the calculation domain. In addition, methodological differences between the CFD simulations of different researchers can also provide significant changes in results. For these reasons, care must be taken to compare different studies about the performance of Savonius wind rotors.

Finally, it is possible to declare that the present research resulted in the gathering of important information about Savonius wind turbines. Discussions about the main parameters that affect the performance of these devices are performed. The reasons for differences between results and the main difficulties in research on the subject are also discussed. It is intended to provide an initial useful knowledge for future studies through this paper.

Acknowledgements

The authors thank the financial support from CNPq through a doctoral scholarship grant to J.V. Akwa, and a scientific productivity grant to H.A. Vielmo.

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